

UNITED STATES PATENT APPLICATION

of

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for

**METHOD AND SYSTEM FOR PROVIDING PROTECTION IN AN OPTICAL
COMMUNICATION NETWORK**

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims benefit of U.S. provisional application serial number 60/398,276 filed July 24, 2002, the entire contents of which are incorporated herein by reference.

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BACKGROUND OF THE INVENTION

Field of Invention

The invention relates generally to optical communication networks and in particular to methods and systems for providing protection in an optical communication network.

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Description of Related Art

Communication networks often include protection mechanisms to reroute signals in the even of a service interruption. Primary causes of service interruption are link failures and networking equipment failures. Link failures may be caused by failure of the transmission medium, such as the cut of an optical fiber cable, or by failure of an active component that affects all the optical channels on a dense wavelength division multiplexed (DWDM) link, such as an optical amplifier. With carrier-class optical networking equipment, the most likely cause of equipment failure is failure of an isolated optical channel interface.

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A variety of protection techniques exist in order to provide protection against service interruption. For example, a 1+1 protection scheme provides a redundant protection path for each working path. A switch at the receiving end of the working path

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can switch to receive the redundant signal on the protection path if signal quality is deteriorated on the working path. Another known protection scheme is 1:1 protection in which a protection path is associated with each working path, but the protection path is not utilized until signal quality is deteriorated on the working path. Another known 5 protection scheme is 1:N protection in which a protection path is associated with multiple working paths. If signal deterioration is detected on one of the working paths, traffic is redirected to the protection path.

BRIEF DESCRIPTION OF THE DRAWINGS

10 Embodiments of the present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present invention, and wherein:

FIG. 1 is a block diagram of a communication network in an embodiment of the invention;

15 FIG. 2 is a block diagram of a communication network in an alternate embodiment of the invention having optical switch control feedback;

FIG. 3 is a block diagram of a communication network in an alternate embodiment of the invention having WDM transmission with multiple switches;

20 FIG. 4 is a block diagram of a communication network in an alternate embodiment of the invention having WDM transmission with a single switch;

FIG. 5 is a block diagram of a communication network in an alternate embodiment of the invention having alternate channel routing;

FIG. 6 is a block diagram of a communication network in an alternate embodiment of the invention having intermediate network elements between source and destination network elements;

FIG. 7 is a flowchart of an exemplary process for providing tandem protection; and

5 FIG. 8 is a block diagram of a communication network having a mesh architecture in an embodiment of the invention.

DETAILED DESCRIPTION OF INVENTION

The following detailed description of embodiments of the invention refers to the 10 accompanying drawings. The same reference numbers in different drawings identify the same or similar elements. Also, the following detailed description does not limit the invention. Instead, the scope of the invention is defined by the appended claims and equivalents thereof.

The invention may be used in a variety of communications networks, including 15 electrical and optical networks, and combination electrical/optical networks. The expression "communicates" as used herein refers to any connection, coupling, link or the like by which signals carried by one system element are imparted to the "communicating" element. Such "communicating" devices are not necessarily directly connected to one another and may be separated by intermediate components or devices. Likewise, the expressions "connected" 20 and "coupled" as used herein are relative terms and do not require a direct physical connection. This invention may be implemented over a physical linear, ring or mesh topology.

FIG. 1 is block diagram of a communication system 100 in an embodiment of the invention. The system 100 includes two network elements 12 and 14. The network elements may be any known network element such as a switch, router, etc. In one embodiment, network elements 12 and 14 may be a CoreDirector® switch available from 5 CIENA Corporation.

Network element 12 includes a number of transceivers 22 and at least one protection transceiver 24. As described in further detail herein, the protection transceiver 24 provides 1:N optical interface protection for transceivers 22. SONET 1:N APS is an example of one type of 1:N optical interface protection. Additionally, it is understood 10 that any number of protection transceivers (M) may be utilized to protect any number of transceivers (N). Thus, M:N optical interface protection may be provided. A switch 26 directs incoming traffic to an appropriate transceiver.

Similarly, the network element 14 includes transceivers 32, at least one protection transceiver 34 and a switch 36. For simplicity, communication is described as 15 transmission from network element 12 and reception at network element 14. It is understood that bi-directional communication may exist between the network elements.

At the output of transceivers 22 and protection transceiver 24 is a splitter 40 that divides the output into at least two diverse communication paths 42 and 44. For the purpose of this description, 2 diverse paths are shown but it is understood that more than 20 two diverse communication paths may be used for higher redundancy. The diverse communication paths 42 and 44 represent separate communication paths between the network elements. These paths may be physically isolated such as separate optical fibers

geographically separated to reduce the likelihood that both paths will be disrupted simultaneously.

At the receiver side at network element 14, an optical selector 50 monitors the signal on each communication path 42 and 44 and selects the diverse communication 5 path having the better signal quality. The optical selector may be a simple, low cost device that monitors the first communication path 42 and switches to the second communication path 44 (or additional path, if available) in the event of a loss of signal (LOS) or loss of modulation (LOM), for example, on the first communication path 42. More complex techniques may be used to detect deterioration of signal quality as 10 described herein. The redundant diverse communication paths 42 and 44 and the optical selector 50 provide optical path protection.

Optical interface protection is not constrained to using SONET 1:N protection. In the same way that SONET 1:N optical interface protection provides service survivability of the SONET signal, aggregated link interfaces on a router could provide survivable 15 paths for IP packets.

FIG. 2 is a block diagram of another communication system 101 in which the network element 14 provides a control signal 52 to optical selector 50 to cause the optical selector 50 to select a different communication path. The network element 14 may be able to detect more sophisticated signal deterioration than the optical selector 50 (e.g. 20 using performance monitoring capabilities located on transceiver 32). This allows the optical selector to be a low cost device that monitors for simple signal deterioration (e.g. LOS). Network element 14 can detect signal quality such as bit error rate, eye pattern, signal-to-noise ratio, etc. If the network element 14 detects deteriorated signal quality,

control signal 52 from network element 14 causes the optical selector 50 to select an alternate communication path.

Table 1 illustrates how selector 50 may be programmed to choose when to connect to diverse optical path 42 or 44.

5 If control signal 52 does not exist (or is not activated), then selector 50 will connect to the diverse optical path with better quality signal. Without control signal 52, if the quality of signal on each diverse optical path is the same, then the selector 50 will not change state.

10 If control signal 52 does exist, then network element 14 will send switch status instructions to selector 50. Selector 50 will follow those instructions if conditions at the detectors for optical path 42 and optical path 44 are normal. Under all other conditions, selector 50 will ignore said switch status instructions from network element 14 and perform as if control signal 52 does not exist.

Detector at Path 42	Detector at Path 44	Control Signal 52	Selector 50 Action
Normal	Normal	None	No Change
		Instruction from NE 14	Follow NE 14 Instruction
Failure/Degraded Signal	Failure/Degraded Signal	None	No Change
		Instruction from NE 14	No Change Ignore NE 14 Instructions
Normal	Failure/Degraded Signal	None	Connect to Path 42
		Instruction from NE 14	Connect to Path 42 Ignore NE 14 Instructions
Failure/Degraded Signal	Normal	None	Connect to Path 44
		Instruction from NE 14	Connect to Path 44 Ignore NE 14 Instructions

TABLE 1

5 FIG. 3 shows an alternate communication system 102 in which the diverse communication paths are implemented using wavelength division multiplexing (WDM). The outputs of transceivers 22 and protection transceiver 24 are divided at splitters 40 and directed into diverse communication paths 42 and 44. At each diverse communication path, the outputs from the transceivers 22 and protection transceiver 24
10 are combined into a WDM signal by WDM equipment (not shown). Prior to arriving at the selectors 50, the WDM signal is demultiplexed. This provides for monitoring of each WDM channel. As discussed above, the selectors 50 direct the higher quality signal to network element 14.

FIG. 4 shows an alternate communication system 103 in which the diverse communication paths are implemented using wavelength division multiplexing (WDM). The outputs of transceivers 22 and protection transceiver 24 are combined into a WDM signal by WDM multiplexing equipment 60. At the output of the WDM multiplexing equipment 60, the combined multiplex of signals is divided at splitter 40 and directed into diverse communication paths 42 and 44. Prior to arriving at WDM demultiplexing equipment 61, the selector 50 chooses the best quality multiplex of signals. This provides for monitoring of many WDM channels simultaneously. The selector 50 directs the higher quality signals to WDM demultiplexing equipment 61. Each WDM signal is then passed to its appropriate transceiver 32 and protection transceiver 34 in network element
20 14.

FIG. 5 is a block diagram of another communication system 104 in which the selectors 50 and 51 are configured to receive optical signals from different diverse optical paths 42 and 44 respectively. This configuration provides network element 14 with information about the health of each diverse communication path 42 and 44 by receiving performance information 5 from transceivers 32 and protection transceiver 34 (e.g. SONET PM) simultaneously.

FIG. 6 is a block diagram of a communication system 105 in another embodiment in which the tandem optical path protection and optical interface protection are provided over a communications network with intermediate network elements located between source and destination network elements.

For sake of illustration, this example describes optical path protection and optical interface protection for a signal transmitted from network element 12 to network element 14. During provisioning of communication paths, two diverse paths (42 and 44) are established between network element 12 and network element 14. The intermediate network element 70 is provisioned to pass signals along to network element 14 using diverse communication path 42 and intermediate network element 80 is provisioned to 15 pass signals along to network element 14 using diverse communication path 44.

For the purpose of this example, network element 70 is defined to terminate the optical signal using an optical to optical (OO) interface. It receives the signal optically and re-transmits an optical signal towards network element 14 without electrical conversion. An example of such a network element may be an optical line amplifier (e.g. 20 Erbium Doped Fiber Amplifier) or an all-optical switch. If WDM transmission is used then network element 70 may be an Optical Add Drop Multiplexer or a Wavelength Selective Optical Switch.

For the purpose of this example, network element 80 is defined to terminate the optical signal using an optical to electronic to optical (OEO) interface. It receives the signal optically, converts the optical signal to an electronic signal and re-transmits a regenerated optical signal towards network element 14. An example of such a network
5 element may be a SONET regenerator (e.g. Section Terminating Equipment or Line Terminating Equipment).

FIG. 7 is a flowchart of a method for providing tandem protection services for one embodiment of this communication system. The method is described with reference to FIG. 2, but may be implemented in a variety of network architecture configurations,
10 including liner point-to-point, ring and mesh.

At step 310 the process begins. At this point, the communications system is operating under normal conditions. For example, under normal conditions, the primary communication path may be defined as diverse communication path 42 and the backup communication path may be defined as diverse communication path 44. In this step, the
15 primary communication path 42 supports communication signals between network elements 12 and 14. Also, under normal conditions, the transceivers 22 and 32 are defined as the working interfaces and the protect transceivers 24 and 34 are unused.

The impact of signal degradation upon the primary communication path 42 will be described first followed by the impact of signal degradation upon a working interface
20 (e.g. transceiver 22 or 32).

At step 321 signal quality on the primary communication path, for example communication path 42, is monitored. In one embodiment, the optical selector 50

monitors signal quality. The associated transceiver 32 may also detect signal quality as discussed herein.

At step 322, it is determined whether the signal quality has deteriorated. The signal deterioration may be detected as a loss of signal (LOS) or Loss of Modulation 5 (LOM), for example, which a low cost optical selector 50 is capable of detecting. More sophisticated signal quality (bit error rate, eye pattern, SONET alarms etc.) detection may be performed by the optical selector 50 or by transceiver 32. The process loops back to step 321 if the signal quality has not been recognized as deteriorated. If signal quality deterioration is detected, the process continues to step 323.

10 At step 323, the optical selector 50 switches to select the backup communication path 44.

At step 324 signal quality on the backup communication path, for example communication path 44, is monitored and it is determined whether signal quality has been restored. If signal quality deterioration continues to be detected, the process moves to 15 step 325. The process advances to step 340 if signal quality is restored to a normal state.

At step 325, it is recognized that all diverse communication paths (e.g. communication paths 42 and 44) have deteriorated and the communication system has failed.

At step 340, the communications system is operating under alternative conditions. 20 For example, under the alternative conditions of this step, the backup communication path 44 supports communication signals between network elements 12 and 14. Also, as under normal conditions, the transceivers 22 and 32 continue as the working interfaces and the protect transceivers 24 and 34 are unused.

At step 341, an optional reversion routine may be implemented to determine when the failed primary communication path 42 is repaired. If it is determined that repair of primary communication path 42 has not occurred, the communications system will continue to operate under the alternative conditions of step 340. If it is determined that 5 repair of primary communication path 42 has occurred and it is able to resume its role supporting communication signals between network elements 12 and 14, the process advances to step 342.

At step 342, the optical selector 50 switches to select the primary communication path 44. The communication signals between network elements 12 and 14 revert to 10 primary communication path 44 and the communication system resumes operation under the normal conditions of step 310.

The impact of signal degradation upon a working interface (e.g. transceiver 22 or 32) is now described. At step 331 signal quality at the working interfaces, for example transceivers 22 and 32, is monitored. At step 332, it is determined whether the signal 15 quality at the interface has deteriorated. Because signal quality is being monitored at an electrical interface, the signal deterioration may be detected using sophisticated measurements such as bit error rate, eye pattern, SONET PM or alarms (e.g. AIS). The process loops back to step 331 if the signal quality has not been recognized as deteriorated. If signal quality deterioration is detected, the process continues to step 333.

At step 333, a protection delay is initiated after the interface (e.g. transceiver 32) 20 detects a deterioration of signal quality. The network elements 12 and 14 initiate a hold-off timer and they wait for a pre-determined time described as protection delay (e.g., 10 milliseconds) to give time for the optical selector 50 to select the best diverse

communication path per steps 321, 322 and 323. Once the protection delay has expired, the process advances to step 334.

At step 334, it is determined whether the signal quality at all interfaces has been corrected or if multiple interfaces continue to be deteriorated. If it is recognized that 5 multiple interfaces continue to be in a degraded condition, the process advances to step 335. Otherwise, the process moves to step 336.

At step 335, it is recognized that steps 321 and 322 were unable to identify signal degradation on the primary communication path because multiple signal degradations still exist after the interface protection delay (step 333). To correct the multiple signal 10 degradations, control signal 52 is used to request that selector 50 switches from receiving signals from the primary communication path 42 to the backup communication path 44 (per step 323).

At step 336, it is determined whether the quality of a single signal continues to be deteriorated. If it is recognized that all interfaces have been corrected from the degraded 15 condition, then the process advances to step 340. If a single signal is not restored, the process advances to step 337.

At step 337, the network elements 12 and 14 initiate the optical interface protection for the single degraded signal. In the embodiment shown, the use of SONET 1:N APS optical interface protection results in traffic being directed from a working 20 transceiver pair 22 and 32 to protection transceiver pair 24 and 34. Using SONET signaling standards switching time is deterministic and complete connection restoration can occur within 50 milliseconds of detecting the signal deterioration. Upon completion, the process moves to step 350.

At step 350, the communications system is operating under alternative conditions. For example, under the alternative conditions of this step, the primary communication path 42 supports communication signals between network elements 12 and 14. However, a signal from one of the transceiver pairs 22 and 32 is now communicated between the 5 protect transceivers 24 and 34.

At step 351, an optional reversion routine may be implemented to determine when the failed transceiver interface 22 or 32 is repaired. If it is determined that repair of transceiver interface 22 or 32 has not occurred, the communications system will continue to operate under the alternative conditions of step 350. If it is determined that repair of 10 transceiver interface 22 or 32 has occurred and it is able to resume its role supporting communication signals between network elements 12 and 14, the process advances to step 352.

At step 352, the network elements 12 and 14 revert the optical interface protection switch and the communication system resumes operation under the normal conditions of 15 step 310.

FIG. 8 is a block diagram of a communication system 106 in another embodiment in which the tandem optical path protection and optical interface protection are provided over a mesh communications network with more than two diverse optical paths between source and destination network elements.

20 For sake of illustration, this example describes optical path protection and optical interface protection for a signal transmitted from network element 12 to network element 14. During provisioning of communication paths, three diverse paths (42, 44 and 46) are established between network element 12 and network element 14. An intermediate

network element 70 is provisioned to pass signals along to network element 14 using diverse communication path 42 and network element 80 is provisioned to pass signals along to network element 14 using diverse communication path 44. Diverse communication path 46 connects network element 12 to network element 14 directly.

5 At the output of transceivers 22 and protection transceiver 24 is a splitter 43 that divides the output into more than two diverse communication paths. This example illustrates three communication paths 42, 44 and 46. The diverse communication paths 42, 44 and 46 represent separate communication paths between the network elements. These paths may be physically isolated such as separate optical fibers geographically
10 separated to reduce the likelihood that all paths will be disrupted simultaneously.

At the receiver side at network element 14, an optical selector 53 monitors the signal on each of the many communication paths (in this example paths 42, 44 and 46) and selects the diverse communication path having the better signal quality. The optical selector may be a simple, low cost device that monitors the first communication path 42 and switches to the second communication path 44 or third communication path 46 in the event of a loss of signal (LOS) or Loss of Modulation (LOM). The redundant diverse communication paths 42, 44 and 46 and the optical selector 50 provide optical path protection.
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For the purpose of this example, network element 70 is defined to terminate the
20 optical signal using an optical to optical (OO) interface. It receives the signal optically and re-transmits an optical signal towards network element 14 without electrical conversion. An example of such a network element may be an optical line amplifier (e.g. Erbium Doped Fiber Amplifier) or an all-optical switch. If WDM transmission is used

then network element 70 may be an Optical Add Drop Multiplexer or a Wavelength Selective Optical Switch. In a mesh network, network element 70 may terminate more than two optical paths. Optical paths 71 and 72 represent alternative optical paths in this mesh network scenario.

5 For the purpose of this example, network element 80 is defined to terminate the optical signal using an optical to electronic to optical (OEO) interface. It receives the signal optically, converts the optical signal to an electronic signal and re-transmits a regenerated optical signal towards network element 14. An example of such a network element may be a SONET regenerator (e.g. Section Terminating Equipment or Line
10 Terminating Equipment). In a mesh network, network element 80 may terminate more than two optical paths. Optical paths 81 and 82 represent alternative optical paths in this mesh network scenario.

In the mesh embodiment, new communication paths may be provisioned when signal deterioration is detected on an existing communication path. For example, if
15 communication path 42 experiences signal degradation, selector 53 switches to communication path 44. Another communication path may be provisioned to provide an optical protection path for the newly selected communication path.

Embodiments of the invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as departure
20 from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.